Recommendations for Addressing Recurring Chemical Incidents at the U.S. Department of Energy

May 2005

Contents

Executive Summary

Two years ago, the U.S. Department of Energy (DOE) was concerned that too many chemical incidents were occurring within the DOE. In response, the Chemical Safety Topical Committee (CSTC)—an organization chartered by DOE and the Energy Facilities Contractors Group (EFCOG)—sponsored a committee made up of contractor and DOE personnel to determine:

- Are a significant number of chemical incidents actually occurring within the DOE complex?
- Is the number of these incidents trending up or down?
- What is the cost of these incidents?
- Do these incidents have common causes?

If incidents were found to be occurring at a significant rate, then the committee was asked to recommend actions to decrease the incident rate.

DOE occurrence reporting records show a rate of chemical incidents across the DOE complex at about one per day over the last seven years, resulting in one fatality and 28 hospitalizations. This rate appeared constant over the seven-year period. Since overall employment within DOE is trending downward, the accident rate is increasing annually on a per capita basis. Because of difficulties in determining both direct costs (e.g., repairing equipment/facilities, employee injuries, etc.) and indirect costs (e.g., revising procedures, increased training, work slowdowns and stoppages during accident investigations and corrective actions implementations, etc.), the actual costs associated with these accidents could not be calculated, but the committee believed them to be substantial.

The committee determined that both the number and the cost of these incidents each year appeared to be significant. So, a subset of incidents was further analyzed to determine potential common causes. The committee looked at 390 of the approximately 2,000 chemically related incidents reported between 1998 and 2002. Results showed:

- Incidents were independent of chemical hazards or chemical types present. No clustering of incidents was observed for reactives, oxidizers, flammables, corrosives, etc.
- Incidents were independent of work being performed. No clustering of incidents was observed for storage, construction, transportation, lab operations, etc.

After further analysis, it became apparent that the primary reason these incidents were occurring was the failure to identify or properly analyze the hazard. Difficulties in identifying specific causes leading to these incidents include:

- *The complexity of the chemistry.* More than 12 million chemicals have been identified, and their reactivities are dependent on the environment, physical form (e.g., fine powder vs. granular), state (e.g., gas vs. liquid vs. solid), and concentration. The problem is exacerbated by the lack of reference materials to address all possible combinations.

- *Chemical safety requirements are complex.* A recent compilation of requirements for chemical storage, use, etc. resulted in the identification of approximately 1,500 requirements from more than 130 sources. These requirements from fire protection, industrial safety, industrial hygiene, and other disciplines did not include any requirements related to off-site transportation or waste. Having so many requirements in so many disciplines leads to "stove piping" and inconsistent application.

These results are consistent with a report published by the U.S. Chemical Safety and Hazard Investigation Board that analyzed 167 industrial chemical incidents.

The team also reviewed the environmental, safety, and health (ES&H) disciplines that are typically responsible for identifying, preventing, and mitigating chemical hazards. The team determined that the scope of chemical safety, as currently implemented, is not well defined, and there seems to be no clear assignment of responsibility. Responsibilities for various aspects of chemical safety are spread across different disciplines. For example, responsibility for identification and analysis of chemical hazards may be assigned to a specific discipline such as an industrial hygienist, chemical engineer, work planner, or chemist. Also, no criteria for education or experience have been developed for those who are expected to perform hazard identification in the area of chemical safety. The committee is recommending that such individuals should receive specific additional Chemical Safety and Chemical Reactivity training and experience beyond their primary discipline, which is necessary to enable them to adequately identify and analyze chemical hazards at both the worker and process levels.

The committee further recommends that chemical safety should be defined and recognized by DOE through the implementation of "Chemical Lifecycle and Safety Management[1]" as part of Integrated Safety Management (ISM). Chemical safety is a sufficiently complex and unique area that requires a diverse team of trained and experienced professionals. Disciplines may include (but are not limited to) chemistry, chemical engineering, fire protection engineering, industrial hygiene, environmental engineering, and biology. Once a Chemical Lifecycle and Safety Management program is implemented, the program owner would become the "single point of contact for all chemical issues" at a DOE site and would be responsible for any associated decisions or analyses. This would ensure that people with the necessary qualifications are involved in chemical safety analyses, which would result in more accurate analysis. Full and complete hazard identification and accurate analysis will lead to improved protective actions and an overall reduction in chemical incidents.

[1] Chemical Lifecycle and Safety Management – Chemical lifecycle management is a term used to describe the management of chemicals from cradle to grave. Chemical safety is a term used to describe the safe use and storage of chemicals. The hybrid term, Chemical Lifecycle and Safety Management is meant to convey the concept of managing the life cycle of chemicals with chemical safety in the context of ISM to ensure that all aspects of chemical safety and management are coordinated together and adequately addressed.

Introduction

During this project's first phase, available data were examined to determine causes and trends of chemical incidents across the DOE complex. The first phase was completed and results were presented to the CSTC and EFCOG in the fall of 2003.

Analyses from this initial effort showed that the DOE complex was averaging one incident each day from 1993 through 2003, even though the number of employees decreased over that time from 140,000 to about 100,000. After careful review of more than 2,000 reported incidents, 500 incidents that involved health and safety were selected for further analysis. The list was further reduced to 390 incidents based on the quality of the data. Of these incidents, 88% were categorized in the DOE Occurrence Reporting and Processing System (ORPS) as "Off Normal," 11% as "Unusual," and about 1% as "Emergency."

Costs of incidents were estimated as being over $2 million annually for ORPS reporting and for Type A and B investigations. These incident costs are considered very conservative estimates since they do not take into account other direct costs (e.g., repairing equipment/facilities, employee injuries, etc.) and indirect costs (e.g., revising procedures, increased training, work slowdowns and stoppages during accident investigations and corrective action implementations, etc.). Another measure of the cost resulting from these incidents is the impact of one fatality and 28 hospitalizations over the last seven years.

No quantitative breakdown was presented for the common cause analysis; however, the team reported that "Failure to Identify the Hazard" was the single largest contributing factor to these incidents. Other possible causes initially listed were:

- appropriate personnel not involved,
- less-than-adequate independence,
- correct output not applied,
- hazard analysis ignored,
- incorrect determination of low-potential event,
- degree of change insufficient to justify new analysis,
- ego,
- upset conditions not considered in the analysis,
- incorrect or inaccurate information used,
- unpredicted situation,
- less-than-adequate analysis methodology,
- lack of ownership, and
- culture.

During the first phase, the team concluded that the hazard could not be analyzed if the hazard had not been identified. The team further recognized that the initial failure to identify the hazard was potentially a precursor for the other identified causes listed above.

In response, the committee concluded that hazard recognition in ISM needs to be strengthened, but this conclusion was not sufficient to provide necessary guidance to help reduce the chemical incident rate. What was needed was a more specific determination of the reason(s) why chemical hazards were not being identified, which would lead to specific recommendations as to how this deficiency could be rectified.

The charter for Phase II of this project was to look at the incidents cited above to determine qualitatively their causes and consequences, the type of work being performed, and the chemical products involved. This information was tabulated and analyzed to determine if any trends could be identified that would point to areas of weakness. This approach was similar to that used by the U.S. Chemical Safety and Hazard Investigation Board (CSB) when they investigated possible root causes for 167 commercial chemical incidents [1].

Discussion

The primary cause attributed to chemical incidents that occurred in the DOE complex was a "failure to identify the hazard" (see Appendix A for a detailed analysis of causes). The CSB analysis of 167 incidents over a 22-year period showed that over 60% of such incidents were caused by inadequate hazard recognition and evaluation [1]. While failure to identify the hazard is a true cause in almost every chemical incident, the designation is too vague to be useful. Further analysis is necessary to gain a deeper understanding of why people in the DOE complex continue to fail in identifying the hazard.

One area of investigation focused on analysis of chemical hazards involved in these incidents. The chemicals included acids, bases, other corrosives, flammable and combustible liquids, oxidizers, water-reactives, shock-sensitive compounds, pyrophorics, explosives, compressed gasses, asphyxiants, toxics, and generally unstable chemicals. For nine incidents, the exact nature of the chemical hazard was unspecified. For analytical purposes, all classes that pose a stability issue (e.g., explosive, water-reactive) were grouped together.

The chemicals involved in the majority of these incidents were not limited to a single hazard class or even to a few classes (see Figure1). (It should be noted that most chemicals involved in these incidents had more than one class of hazard.) These results were consistent with earlier observations by the CSB [1]. The CSB observed no clustering of incidents involving acids, oxidizers, monomers, water-reactives, bases, alcohols, organic peroxides, inorganics/metals, or other chemical classes.

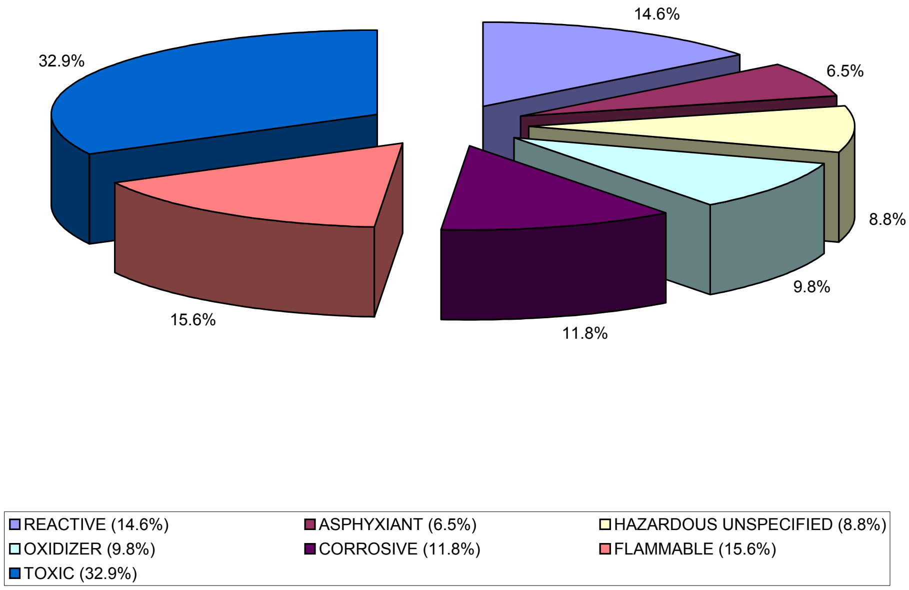

Figure 1 – Occurrences by Chemical/Hazard Classification

Since no clustering of chemical classes was observed in these incidents, the team speculated that some other common factor might be involved. Perhaps the chemicals involved in these incidents might cluster around chemicals that are regulated by the Occupational Safety and Health Administration (OSHA) and the Environmental Protection Agency (EPA). OSHA's regulation, *Process Safety Management of Highly Hazardous Chemicals* (29 CFR 1910.119), covers approximately 130 chemicals that have the potential for causing or being involved in chemical incidents. Likewise, EPA's regulation, *Chemical Accident Prevention Provisions* (40 CFR 68), lists approximately 70 chemicals that are to be evaluated. Of the 390 chemical incidents that were analyzed, only 30 involved regulated chemicals on either of these lists. Once again, the absence of incident clustering observed here was consistent with that found by the CSB [1]. The CSB observed that less than 40% of the chemical incidents they investigated involved regulated chemicals.

The hazard rating system described in National Fire Protection Association (NFPA) 704, *Standard System for the Identification of the Hazards of Materials for Emergency Response*, was then examined. An effort was made to determine if chemicals involved in these incidents had a high instability (formerly reactivity) hazard rating according to NFPA 704 criteria. Of the 390 chemical incidents, ratings were published for only 145 and, of those, 47 had hazard ratings of "0" or "1," indicating low hazard. These results mirrored those of the CSB, which reported that chemicals with high instability ratings were not always involved in chemical incidents. The CSB found that almost 70% of the chemicals involved in the incidents they investigated were either unrated or had an instability rating of "0" or "1." In the DOE analysis, 75% of the incidents involved chemicals with either no instability rating or a rating of "0" or "1." This would indicate that NFPA hazard ratings have a limited potential as a screening tool to predict chemical incident scenarios.

The next line of inquiry involved the type of work being performed during the incident. Analysis indicated that the type of work was not a factor (see Figure 2). Work involving chemicals that resulted in incidents included laboratory experimentation, storage, process operations, transportation, etc. Equipment used in each incident also varied widely, eliminating another possible factor. The same was true of incident types. Incident types varied (e.g., spills, fires, explosions, exposures), and no one type of incident occurred at a significantly greater rate. Once again, these results were similar to those reported in the CSB investigation [1].

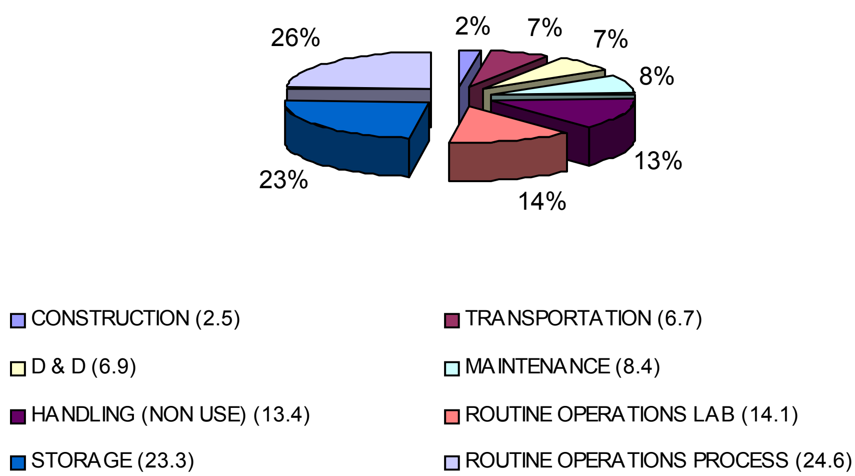

Figure 2 - Type of Work Performed vs. Chemical Incidents

This analysis and other similar analyses (e.g., CSB) indicate that few, if any, chemical incidents are similar. The various incidents involve different chemicals, at different concentrations, in different environments, in different uses, and with different pieces of equipment. This means that no simple fix can be engineered to address specific chemicals, processes, equipment, or environments. Thus, the true issue to be addressed—the factor that makes it difficult to identify hazards—is the "complex and difficult nature of chemical safety."

Complex Nature of Chemical Safety

One of the reasons for the complex nature of chemical safety is the huge number of chemicals and their tendency to react with other chemicals in the process or in the environment. Currently, there are more than 12 million known chemicals, with more being discovered daily. Each of these chemicals can undergo many reactions. Moreover, not all reactions are well known or documented, even for well-researched chemicals. Additionally, these reactions are dependent on concentration, temperature, physical form (e.g., fine powder vs. granular), state (e.g., gas vs. liquid vs. solid), presence of contaminants that could catalyze or inhibit reactions, etc. Variabilities of temperature, coreactants, concentration, contaminants, etc., are too complex to be captured in a document as simple as a Material Safety Data Sheet (MSDS) or any other single reference.

Another factor contributing to the complexity of chemical safety is the multitude of chemical regulations that various federal agencies have promulgated [e.g., DOE, EPA, OSHA, and the Department of Transportation (DOT)] as well as various consensus standards that DOE Orders have incorporated [e.g., NFPA, Compressed Gas Association (CGA) and local fire codes]. DOE recently published a partial listing of chemical safety regulations from Federal sources [2]. This listing did not include requirements for waste, off-site transportation, or local regulations and still contained approximately 1,500 requirements from more than 130 sources. This represents an extraordinary number of regulations to be understood and implemented.

Another reason for the complex nature of chemical safety involves chemicals with multiple hazardous properties (e.g., an oxidizing acid or a combustible acid). For such chemicals, it is sometimes difficult to reconcile conflicting requirements in various controlling regulations. Examples include:

- If an acid is controlled by rules regulating corrosives and you want to dilute the acid, then at what point is the acid no longer considered a corrosive that is governed by those rules?
- When NFPA codes require a water-based fire suppression system for flammable liquids, then how do you store a flammable liquid that also happens to be a water-reactive material?
- What regulations take precedence for a highly toxic, flammable gas – those for highly toxic gases or those for flammable gases?

Questions such as these are routinely encountered, and often no easy answer is available.

Currently Used Systems

Numerous attempts have been made to develop systems that will result in safer chemical usage, but these have not been as successful as developers had hoped. Some of these systems are developed around hazard types, but as shown above, some chemicals do not fit neatly into hazard categories.

One system is based on the Process Safety Management (PSM) regulation. PSM contains a list of approximately 130 chemicals that are used in industry. This regulation stipulates that, if any chemical on the list is present in quantities greater than or equal to those listed, then various actions must be taken to more safely operate the process using the chemical. This type of system has its own weaknesses. First, the list is not all-inclusive. Many more chemicals than the 130 on the list are used routinely in the DOE complex. If a chemical is not on the list, or is on the list but in quantities below the regulatory threshold, then the process does not require analysis under the regulation. Another weakness with this type of system is that it tends to provide a false sense of security. If no listed chemical is involved in the work to be performed, the worker tends to feel safe in that there are no chemical hazards to consider.

Another system uses specific hazard ratings to identify potential chemical hazards. One weakness of using ratings to screen for hazards is that not all chemicals have been rated. If the chemical in question has not been rated, the system cannot be used for analysis. Also, chemical hazard ratings are based on hazards present in a given standard set of conditions that may or may not represent the existing conditions for the process being evaluated. If conditions for the process are different than those used to develop the ratings, the published ratings may provide an inaccurate picture of incident potential. Lastly, focusing on specific chemical hazard ratings can cause other issues to be ignored. The CSB reported that too narrowly focusing on toxicity hazards resulted in an incident because other chemical hazards present were not evaluated [3].

A third system assigns various aspects of chemical safety to different organizations/ disciplines (i.e., "stovepiping"). A typical approach assumes that the industrial hygienist should be responsible for IH issues such as personal protective equipment (PPE) and monitoring, that a fire protection professional should be responsible for issues such as NFPA regulations (e.g., the "NFPA Diamond" from NFPA 704), etc. This leads to a fragmented program that typically has many holes in the coverage and can be inconsistent from organization to organization.

One aspect in common with all of these systems is that chemical safety is already typically assigned to traditional disciplines such as industrial hygiene or chemical engineering. If chemical safety is to be the responsibility of industrial hygiene, chemical engineering, or any other individual technical discipline, then the personnel involved should have sufficient qualifications and/or experience to identify and analyze the hazards.

Recommendations

Because previous solutions to prevent chemical incidents have not been as successful as desired, other approaches must be devised. These approaches must avoid "stovepiping," must ensure that people with the necessary education and experience are involved, and must promote a clear understanding of regulations and their intents. To accomplish this, two steps are recommended.

<u>Recognition of Chemical Lifecycle and Safety Management</u>

First, Chemical Lifecycle and Safety Management should be recognized as a unique safety subject area as a part of ISM. Chemical Lifecycle and Safety Management is not an easy area to understand given the large number of regulations and its technical aspects, as is the case for other safety disciplines (e.g., fire protection, industrial safety, and industrial hygiene). If the overall cause for these chemical incidents is a failure to identify the hazards, then site management needs to improve compliance with ISM, which includes the core functions of "Analyze the Hazard" and "Develop and Implement Hazard Controls."

Managers need to recognize that Chemical Lifecycle and Safety Management is a separate discipline. They need to understand that it is not an easy area to understand, and they must ensure that they have the resources to cope with its complex technical aspects. Managers also need access to individuals who have critical chemical knowledge, including an understanding of chemical thermodynamics, reactivity hazards, chemical process hazards, and explosion hazards. Laboratory or chemical process knowledge and experience are also crucial, because they provide hands-on knowledge of chemical behavior, limitations of laboratory or chemical process equipment, and potential alternatives that would make the work safe. Knowledge of hazardous materials response is also useful.

A chemical safety professional should understand certain critical concepts such as chemical thermodynamics, redox reactions, reactivity as a function of surface area, the Carnot cycle (including concepts such as adiabatic compression), and reaction energies (e.g., Gibbs free energy, heats of combustion, entropy). These and other important concepts are not covered in detail until advanced chemistry courses.

Chemical safety professionals should also have laboratory or other hands-on experience because:

- They receive hands-on knowledge about what chemicals can do.
- They learn how various pieces of laboratory or industrial equipment (including analytical instrumentation) work and what their limitations are.
- They are familiar with various standard laboratory or production activities, which helps them design methods to mitigate chemical hazards that will not hinder the work being performed.

Lastly, chemical safety personnel should have training or experience in hazardous materials response. This would provide them with practical information about the recognition, prevention, and mitigation of the potential of chemical incidents.

Ownership

Second, management needs to establish ownership for Chemical Lifecycle and Safety Management, so that people will know where to go for authoritative chemical safety answers. The owners of Chemical Lifecycle and Safety Management would have a responsibility to ensure that the correct analysis was performed and the best answer was given. Having ownership over a defined area of safety forces one to take ownership of analyses that are performed and answers that are given in order to determine if an activity can be performed safely. This, in turn, forces the owner to ensure that those involved in the analyses and decision-making are qualified. Additionally, the owner of the Chemical Lifecycle and Safety Management program would become the “Single Point of Contact for all Chemical Issues” at any given DOE site.

These recommendations are consistent with the first guiding principle of ISM: “Line Management (is) Responsible for Safety.”

References

1. U.S. Chemical Safety and Hazard Investigation Board, "Hazard Investigation: Improving Reactive Hazard Management," Report No. 2001-01-H, NTIS No. PB2002-108795, CSB, Washington, D.C. (December 2002).

2. DOE Chemical Management Handbook, Volume 3, "Consolidated Chemical User Safety and Health Requirements," DOE-HDBK-1139/3-2003

3. U.S. Chemical Safety and Hazard Investigation Board, "Dust Explosion: West Pharmaceutical Services, Inc.," Report No. 2003-07-I-NC, CSB, Washington, D.C. (September 2004).

4. DOE Occurrence Reporting and Processing System (ORPS) http://www.eh.doe.gov/paa/orps.html

Attachment A – Supporting Analysis (Causes)

As seen in Figure A-1, the failure to correctly identify hazards, combined with inadequate hazard evaluation (which includes hazard analysis and the identification of appropriate controls), constituted the bulk of all causes contributing to the ORPS incidents. Since storage and labeling practices are inherently based on hazard evaluation (e.g., the requirement for segregation of incompatible chemical classes), it is reasonable to surmise that, at a minimum, 60% of the causes are due to inadequate hazard identification.

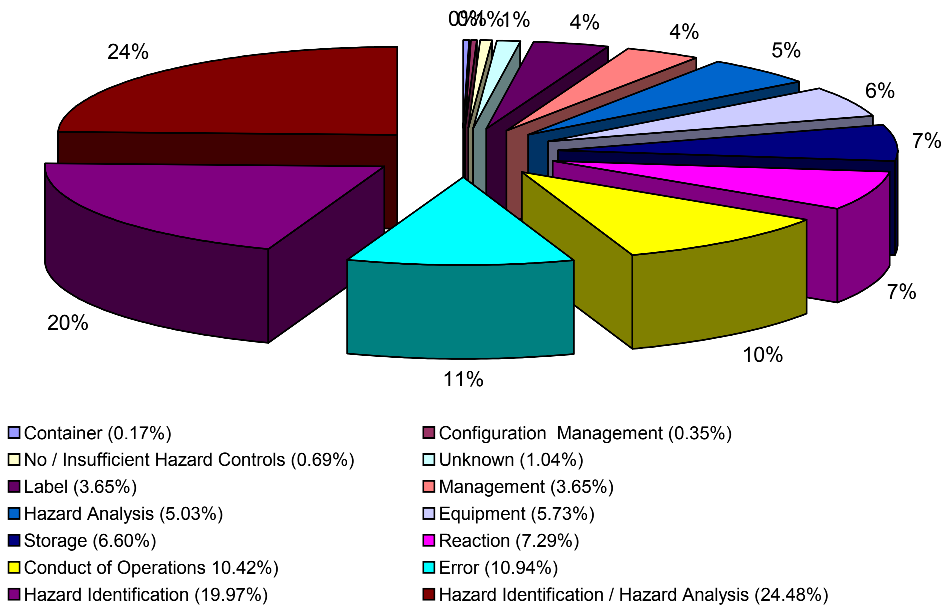

Figure A-1 – Causes
(Note: Some incidents had multiple causes)

Conduct of operations and human error contributed equally (at 10% each) to these chemical occurrences. Chemical reactions contributed 7%. Management deficiencies and equipment inadequacies accounted for the remainder of causes, with 1% being unknown (i.e., a specific cause could not be assigned). Since management, human error and conduct of operations issues are DOE site-specific and can be addressed by strengthening training, this report focuses on the single issue that stands out as a major contributor to these incidents, namely “Failure to Identify Hazards.”

Attachment B – Team Members

Team Leads

James Morgan	Westinghouse Savannah River Corporation (WSRC)
Fred Simmons	WSRC

Team Members

Michael Blackwood	Retired
Kim Delman	DOE-Albuquerque
Dave Freshwater	SAIC
Murty Kuntamukkula	WSRC
Billy Lee	DOE Headquarter, EH-52
Dave Quigley	BWXT, Y-12
Robert Vrooman	DOE-National Nuclear Security Administration, (NNSA-Albuquerque)
Steve Wilson	WSRC